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Seasonal dynamics in the relative density of aquatic flora along some coastal areas of the Red Sea, Tabuk, Saudi Arabia

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KEYWORDS

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Abstract Plants are the producers of all autotrophic ecosystems' and are the base of the food chain taking energy from the sun and converting it into food for all other organisms through photosynthesis. Plants grow in certain places and seasons when the environmental factors are suitable for their germination, growth and developments that influence their diversity. Environmental factors can include abiotic factors such as temperature, light, moisture, soil nutrients; or biotic factors like competition from other plants or grazing by animals. Anthropogenic perturbations can also influence distribution patterns. Monitoring of ecological habitats and diversity of some aquatic flora along some coastal areas of Red Sea has been done to understand the dynamics of aquatic plants influenced by prevailing environmental and anthropogenic perturbations The results of this research showed that the summer season is the most suitable period for the study of aquatic plant diversity along the coastal sites of Red Sea. The aquatic flora had high relative density and diversity in April, May, June and July and these four months of the summer season are best for collection of aquatic plants from the selected coastal areas of Red Sea for medicinal purposes and ecological studies.

Introduction

Biological diversity refers to numbers of different species of plants and animals in an environment. More than 1.7 million species of organisms have been named so far and is continuing to turn up new species at the rate of approximately 15,000 per year. Among them, aquatic ecosystems support a very rich biodiversity (Agarwal and Agarwal, 2007; Sharma, 2005; Ansari and Gill, 2016a). The Species extinction across the globe is mainly governed by changing environmental conditions leading to habitat destruction. Among all, the most important abiotic environmental factors are level of nutrients like nitrogen, phosphorus, calcium, atmospheric CO_2, pH, and climate changes including temperature, light and precipitation. Relative densities of primary producers, consumers like herbivores and carnivores, pathogens, predator species and human population are some biotic environmental factors causing perturbations in biodiversity patterns. Extinction of species would occur because the physiologies, morphologies, and life histories of plants that limit each species to a particular combina-

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tion of environmental constraints (Tilman and Lehman, 2001). A regular monitoring and assessment is required to conserve the ecological habitats and diversity of aquatic flora, as they play very significant roles in energy production, energy flow, pollutants removal and biogeochemical cycling of nutrients in aquatic ecosystems (Ansari et al., 2011a). Phytoplankton community structure and diversity are considered as an ecological indicator for the monitoring and assessment of aquatic environment (Ansari et al., 2016b).

Understanding the mechanism behind the biological diversity patterns in terrestrial and aquatic ecosystems is accepted as a great challenge by the scientific world of today. The studies on species diversity in aquatic ecosystems are much ignored as compared to terrestrial and benthic ecosystems because of the scarcity of experimental data due to unstable conditions of the aquatic environment (Murphy et al., 2003). The excessive addition of pollutants to water causes quality problems and is one of the major causes of habitat destruction and diversity changes in aquatic ecosystems (Ansari et al., 2015). Due to ubiquitous water pollution, many plant species are actually threatened and results into a temporary or permanent change in species composition. Succession of phytoplankton community may occur due to the ecological and environmental conditions (Xiao et al., 2016). The species that can adopt and tolerate the changing environmental conditions are more competitive and had better means of its diversity as compared to the species that have low tolerance limits and are very sensitive to any change (Romermann et al., 2008). The plant species are primary producers and form the important component governing the structure and functioning of an aquatic ecosystem. Area, altitude, trophic status and water quality are the important parameters used to estimate the species richness in aquatic ecosystem. Due to anthropogenic threats and global climate changes the plant diversity is potentially threatened (Murphy, 2002; Ali and El-Magd, 2016). Aquatic macrophytes are photosynthetic organisms, which actively grow permanently or periodically submerged below, floating on, or growing up through the water surface (Chembers et al., 2008). High nutrient concentrations enhance the excessive growth of phytoplankton and macrophytes in the aquatic ecosystem (Rovira and Pardo, 2006). Spatial structure of the phytoplankton community is the direct effect of climatic conditions and physicochemical characteristics of water play a minor role. Floristic structure of the phytoplanktons is influenced by abiotic factors of the aquatic environment (Gabyshev and Gabysheva, 2016).

Materials and methods

Qualitative survey for the diversity of aquatic flora in terms of relative density was carried out on monthly basis (October 2014–September 2015) to investigate the impact of varying environmental conditions on species structure. Three coastal stations of the Red Sea at Haql (29°17′9.9″N 34°56′18.9″E), Sharmaa (28°1′27.9″N 35°16′9.9″E) and Duba (27°20′57.3″N 35°41′46.2″E) near Tabuk, Saudi Arabia were selected to study the seasonal dynamics and diversity of aquatic flora (Fig. 1). After every 200 meters five sampling sites from each station (Haql, Sharmaa and Duba) were selected. Five different sites were considered as replicates for each station. Qualitative survey for the relative density of aquatic flora along the selected coastal areas of the Red Sea was carried out using quadrates of 1 m^2. Data were analyzed statistically for the significance of research using computer software SPSS V. 16 for Windows statistical analysis). The data were subjected to a one way ANOVA with least significance difference (LSD) tests at a significance level of ($p < 0.05$).

To determine the seasonal dynamics in diversity and distribution of aquatic flora along the coastal areas studied in this research, relative densities were calculated as:

$$\text{Relative Density } D_r = \frac{a}{b} \times 100$$

a = Total No. of individuals of plant species in all the sampling units; b = Total No. of sampling units studied.

Relative density in terms of occurrence and water surface occupied was expressed in following six quantitative classes shown in Table 1.

Results

At the selected coastal sites of the Red Sea of Haql, Tabuk, Saudi Arabia, *Jania rubens* showed higher densities in October-14 and May-15. Least occurrence of this species was observed in March-15. This plant species disappeared in November, December 2014 and August, September 2015. Relative density of *Gastroclonium ovatum* was at its peak in October-14 and July-15, where as it was lowest in February-15. *G. ovatum* was not found on any site in January and May 2015. *Padina pavonica* showed higher density in the month of June-15 and lower in February-15. This plant species was not found at any site of Haql in December-14 and January-15. Relative density of *Hildenbrandia rubra* was maximum in July-15 and minimum in October-14. Non-occurrence of the species was observed in November, December-14 and February, March-2015 (Fig. 2 and Table 2).

Nemalion helminthoides occurance was higher in February-15 and lowest in July-15. Existence of this plant species was not recorded in October-14 May, June, August, and September-15. *Polyides rotundus* showed a higher relative density in August-15 but lower in April-15. Plant samples of this species were not found at any site of Haql station in December-14 and January, March 2015. *Cladophora prolifera* was shown the high density in July-15 but very low relative density of this species was recorded in April-15. This plant species disappeared from all the study sites of Haql in November and December-14. *Ulva lactuca* showed higher relative density in April-15 whereas density was low in January-15. Non-occurrence of this species was recorded in November, December-14 and February-15. *Enteromorpha flexuoca* was observed in almost all the seasons of Tabuk with maximum relative density in July-15. The density of *E. flexuoca* was low in November-2014. *Pterocladia capillacea* also showed higher density in most of the seasons. Highest relative density of this species was recorded in July-15 and lowest in March-15. Samples of this plant species were not found at selected sites of Haql station in the month January and February 2015. The aquatic alga *Gracilaria salicornia* was densely populated in July-15 whereas density of this species was lowest in January-15. An irregular appearance and disappearance of *G. Salicornia* were recorded in different seasons (Fig. 2 and Table 2).

Relative density of *Digenia simplex* was maximum in June-15 and lowest in February-15. Non-occurrence of this plant species was observed in November, December-14 and

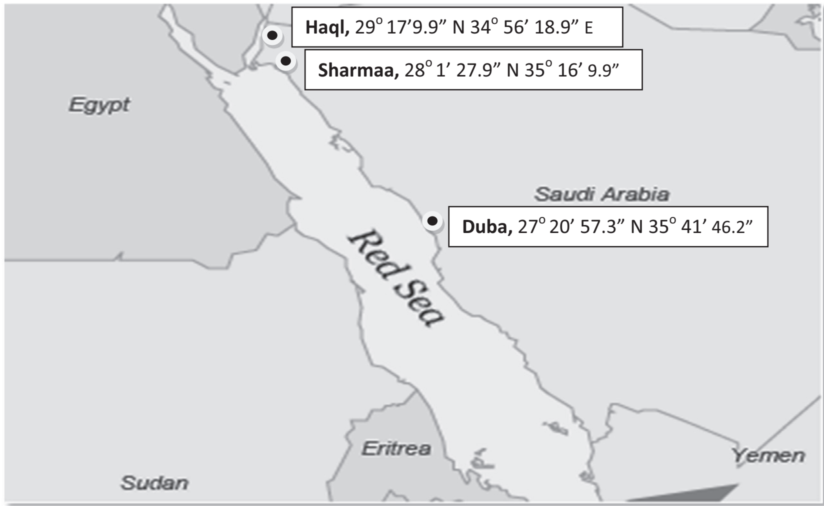

Figure 1 Coastal stations of the Red Sea selected for study of the seasonal dynamics in floral diversity.

Table 1 Relative density measured in six quantitative classes.

S. No.	Relative density (%)	Quantitative classes
1	0	– (non-occurrence of a species)
2	1–20	a (very low density of a species with sporadic occurrence)
3	21–40	b (low density of a species)
4	41–60	c (medium density of a species)
5	61–80	d (high density of a species)
6	81–100	e (very high density with the dominance of a single species)

September-15. *Chaetomorpha linum* showed its highest relative density in June-15 and lowest in April-15. *C. linum* disappeared from five selected sites of Haql in December-14 and January, February, August and September-15. Among the different plant species recorded from five coastal sites of Haql, *E. flexuoca, P. capillacea, C. prolifera, P. pavonica* and *U. lactuca* showed higher relative densities as compared to the other plant species. Floral diversity was higher in the summer season as compared to other seasons. In the months April, May, June and July-2015 most of the plant species were blooming along five coastal sites of the Red Sea at Haql (Fig. 2 and Table 2).

At the selected coastal sites of the Red Sea of Sharmaa, Tabuk, Saudi Arabia, *Jania rubens* showed higher densities in April and May-15. Least occurrence of this species was

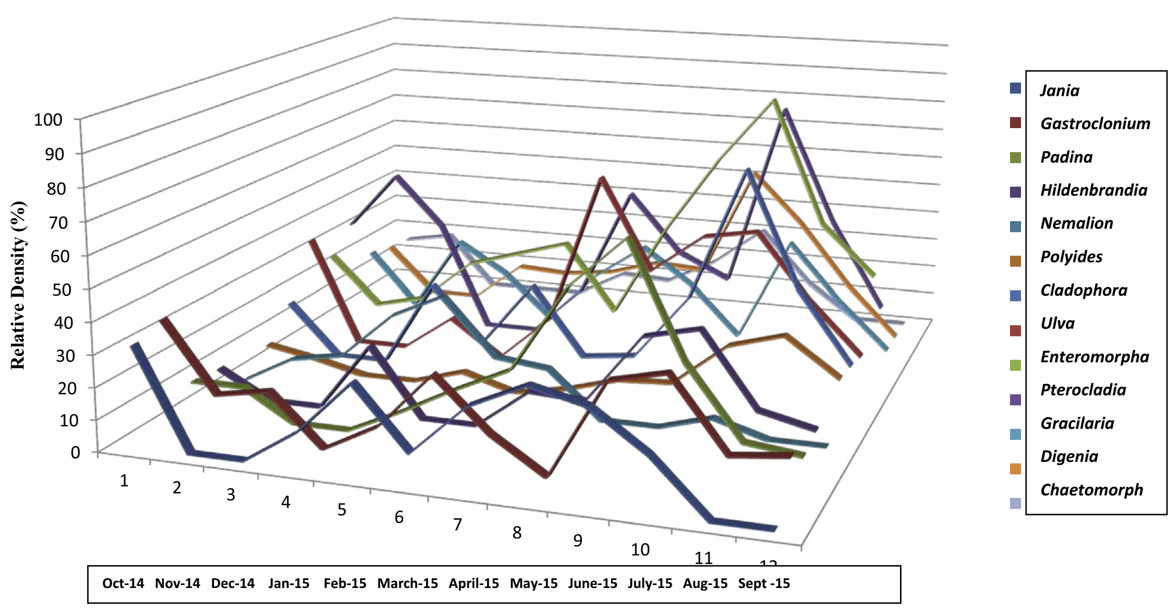

Figure 2 Seasonal dynamics in relative density of aquatic flora along the selected coastal sites of the Red Sea at Haql, Tabuk, Saudi Arabia.

Table 2 Seasonal dynamics in relative density of aquatic flora along the selected coastal sites of the Red Sea at Haql = H, Sharmaa = S and Duba = D in Tabuk, Saudi Arabia.

Plant samples	Relative density measured in six quantitative classes (%)																																				LSD at 5%
	Oct-14			Nov-14			Dec-14			Jan-15			Feb-15			March-15			April-15			May-15			June-15			July-15			Aug-15			Sept-15			
	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	H	S	D	
Jania rubens	b	a	a	–	a	b	–	–	a	a	–	b	b	–	–	a	a	b	b	b	b	b	b	b	b	a	c	a	a	a	–	–	a	–	–	–	3.63
Gastroclonium ovatum	b	a	a	a	a	–	a	–	a	–	–	–	a	–	a	b	–	–	a	–	a	–	a	a	b	a	b	b	–	b	a	–	a	a	–	a	4.54
Padina pavonica	a	b	b	a	a	a	–	–	b	–	–	–	a	–	–	a	a	a	b	–	a	c	a	b	d	b	c	b	b	a	a	a	b	a	a	a	7.35
Hildenbrandia rubra	a	a	a	–	–	–	–	–	–	b	a	a	–	b	a	–	–	a	a	a	–	a	a	a	b	c	b	b	b	b	a	a	a	a	–	–	4.62
Nemalion helminthoides	–	–	–	a	a	a	a	–	a	b	b	b	b	a	b	a	a	a	a	a	a	–	a	–	–	–	–	a	a	–	–	–	–	–	–	–	5.22
Polyides rotundus	a	a	a	a	–	–	–	–	–	–	–	–	a	–	a	–	–	a	a	–	a	a	–	a	a	a	d	b	c	b	b	a	b	a	a	a	3.79
Cladophora prolifera	a	–	–	–	a	–	–	a	–	b	b	a	a	–	a	b	b	a	a	a	a	a	–	a	b	b	a	d	a	b	b	a	b	a	–	a	8.65
Ulva lactuca	b	a	c	–	–	a	–	–	a	a	a	b	–	a	a	a	a	a	d	e	c	b	d	c	c	b	e	c	b	b	b	b	a	a	–	a	9.21
Enteromorpha flexuoca	b	a	a	a	a	a	a	b	b	b	b	b	b	a	a	b	a	b	a	a	c	c	b	d	d	b	b	e	a	e	c	a	b	b	a	a	10.51
Pterocladia capillacea	b	a	b	c	–	–	b	a	–	–	a	a	–	–	a	a	–	a	c	a	b	b	a	b	b	a	a	e	d	b	c	b	a	a	a	a	9.67
Gracilaria salicornia	a	a	–	–	–	–	b	–	a	a	–	a	–	–	a	a	a	a	b	–	a	a	b	–	–	a	b	b	a	a	a	a	a	–	–	–	7.20
Digenia simplex	a	a	a	–	–	–	–	a	–	a	a	b	a	–	b	a	b	a	a	–	c	a	a	b	c	b	a	b	a	b	a	–	–	–	–	–	5.43
Chaetomorpha linum	a	–	a	a	–	–	–	a	–	–	–	a	–	–	a	a	a	a	a	–	a	a	a	a	b	a	a	a	a	a	–	–	–	–	–	–	4.25

Each value is a mean of data collected from 5 different sites (S1–S5) at each station.

observed in October-14. This plant species disappeared from the study sites in December 2014 and January, February, August, September 2015. Relative density of *G. ovatum* was higher in November-14, whereas the species was not found at any site in the rest of the study period. *P. pavonica* showed high relative density in the month of October-14 and June, July-15 and lower in March-15. *P. pavonica* disappeared from all the selected sites of Sharmaa in December-14 and January, February, April-15 (Fig. 3 and Table 2).

Relative density of *H. rubra* at selected sites of Sharmaa was maximum in June and minimum in January-15. Non-occurrence of the species was observed in November, December-14 and March, September-2015. *N. helminthoides* density was higher in the months of January, February-15 and lower in July-15. Occurence of *N. helminthoides* was not recorded in October-14, June, August, September-15. *P. rotundus* showed high relative density in July-15 but lowest in October-14. Plant samples of this species were not found at any site of Sharmaa station during most of the study period. *C. prolifera* showed high relative density in June-15 but very low in December-14 and disappeared in October-14 and February, May, September-2015. *U. lactuca* showed highest relative density in April, May-15 and lowest in January-15. Non-occurrence of this species at selected sites of Sharmaa was recorded in November, December-14 and September-15 (Fig. 3 and Table 2).

E. flexuoca was observed in almost all the seasons of Tabuk and showed its maximum relative density in May, June-15. The density was lower in the month of September-2015. *P. capillacea* showed higher relative density in July-15 and lowest in January-15. Samples of this plant species were not found at different sites of Sharmaa station in the month of November-14 and February, March-2015. *G. salicornia* showed high density in May-15 whereas density of this species was lowest in March-15. Disappearance of this species was recorded in November, December-14 and January, February, April, September-15. Relative density of *Digenia simplex* was maximum in March-15 and minimum in October-14. Non-occurrence of this plant species was observed in November-14 and February, August, September-15. *C. linum* showed its highest relative density in May, June-15 and lowest in December-14. In the rest of the months this species was not recorded from all the five selected of Sharmaa. Among the different plant species recorded from five coastal sites of Sharmaa *U. lactuca Pterocladia capillcea, H. rubra, P. rotundus, E. flexuoca* and *C. prolifera* showed higher relative densities as compared to the other plant species. Floral diversity was higher in the summer season as compared to other seasons at this site. In April, May, June and July-2015 most of the plant species existed along the five coastal sites of the Red Sea at Sharmaa (Fig. 3 and Table 2).

At the selected coastal sites of the Red Sea of Duba, Tabuk, Saudi Arabia, *Jania rubens* showed higher densities in June-15. Least occurrence of this species was observed in October-14. This plant species disappeared from the study sites in February and September 2015. Relative density of *G. ovatum* was higher in June and July-15 and lower in September-15. The species was not found at Duba in November-14 and January, March 2015. *P. pavonica* showed high relative density in the month of June-15 and low in September-2015. Disappearance of the species was observed at all the selected sites of Duba in January and February-15.

The relative density of *H. rubra* at Duba was maximum in June, July-15, whereas it was minimum in October-14. Non-

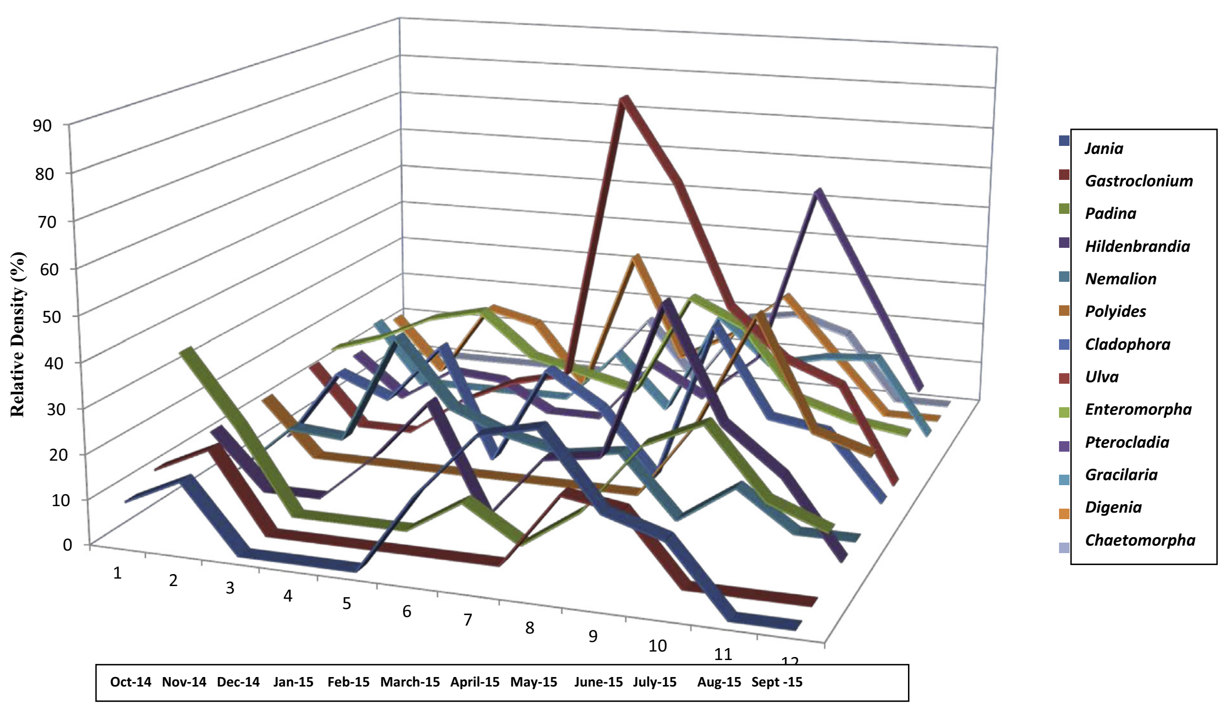

Figure 3 Seasonal dynamics in relative density of aquatic flora along the selected coastal sites of the Red Sea at Sharmaa, Tabuk, Saudi Arabia.

occurrence of the species was observed in November, December-14 and April, September-2015. *N. helminthoides* density was higher in the month January, February-15 and lower in April-15 and nil in October-14 and May to September-15. *P. rotundus* showed high relative density in June-15 and lowest in October-14. Plant samples of this species were not found at any site of Duba station during November, December-14 and January 2015. *C. prolifera* showed high relative density in July, August-15 but very low in June-15 and disappeared in October, November and December-14. *U. lactuca* was found at all the study sites of Duba in almost all the seasons and showed highest relative density in June-15 and lowest in March-15 (Fig. 4 and Table 2). *E. flexuoca* was also observed in all the seasons and showed its maximum relative density in July-15. The density was lower in the month of October-2014. *P. capillacea* showed high relative density in May-15 and lower in August-15 and nil in November, December-2014. *G. salicornia* showed higher density in June-15 and lowest in March-15 at Duba. This species disappeared in November, December-14 and September-2015. Relative density of *Digenia simplex* was maximum in April, May-15 and minimum in March-14. Non-occurrence of this plant species was observed in October to December-14 and August, September-2015 (Fig. 4 and Table 2).

C. linum showed its higher relative density in October-14 and July-15 and lower in February-15. Non-occurrence of this plant species was observed in October to December-14 and August, September-2015 at five study sites of Duba. Among the different plant species recorded from five coastal sites of Duba *U. lactuca, E. flexuoca, P. rotundus, P. pavonica* and *Jania rubens* showed higher relative densities as compared to the other plant species. Floral diversity was higher in the summer season as compared to other seasons. In the months April, May, June and July-2015, most of the plant species existed along five coastal sites of the Red Sea at Duba (Fig. 4 and Table 2).

Discussion

During the summer season coastal aquatic flora of the Red Sea at different selected sites showed high relative densities. During the different months of this study April, May, June and July of the summer season were the best period to study sand collection of aquatic flora. The environmental conditions especially temperature and light may be the reasons for blooming of flora during these months. The following research needs to be extended to study the changes in aquatic plant biodiversity in coastal ecosystems in response to the dynamics in climatic conditions of Tabuk. The Tabuk region of Saudi Arabia is characterized by highly variable environmental conditions where temperature, rainfall, wind velocity and light vary from extremely low to extremely high and affects the morphology, growth, physiology, biochemistry, occurrence and disappearance of a particular plant species. Detailed studies are needed to determine the impact of different environmental factors on biodiversity of aquatic flora along the coastal areas of the Red Sea in Saudi Arabia.

High chemical or physical stress enhances the struggle for survival in perturbed ecosystems. As a result the diversity of organisms declines in perturbed ecosystems as compared to the normal one (Ansari, 2005; Ansari and Khan, 2006, 2009a). Aquatic ecosystems depend on many factors, including retention time, season, temperature, pH, diversity of species, nutrients loading, hydraulic regimes, plant harvesting and light

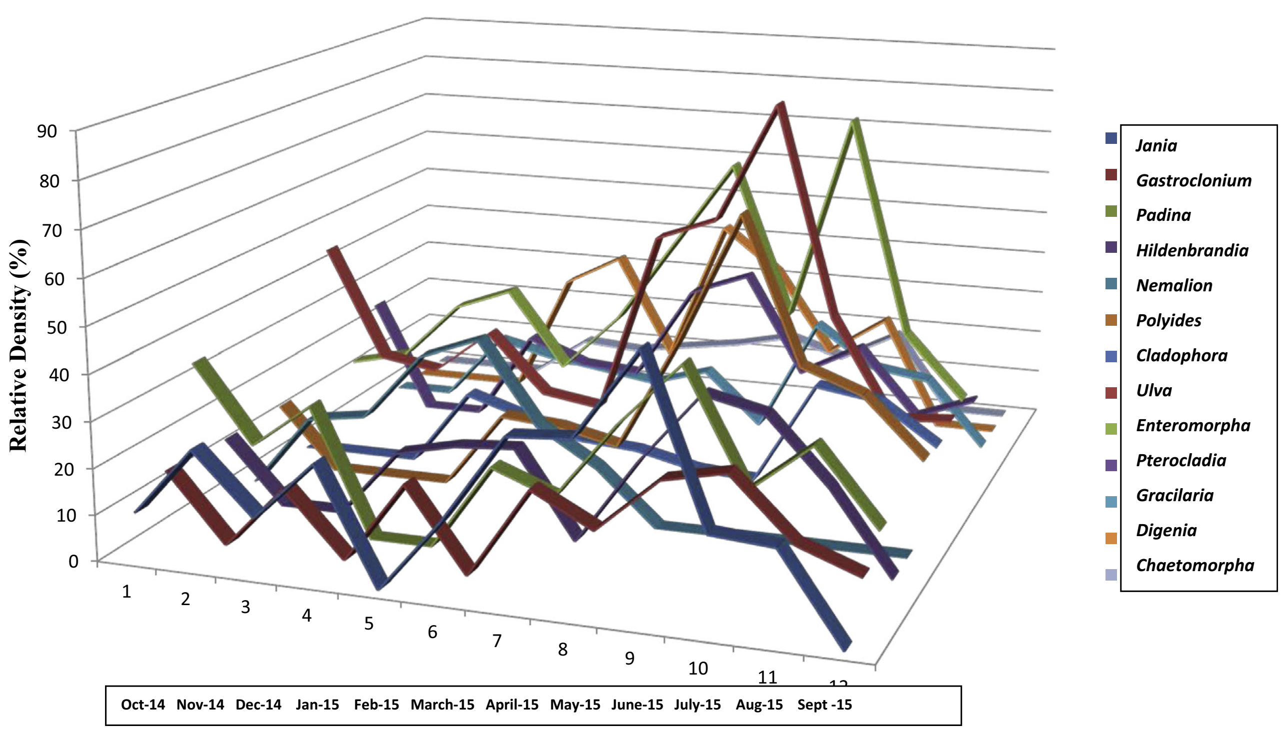

Figure 4 Seasonal dynamics in relative density of aquatic flora along the selected coastal sites of the Red Sea at Duba, Tabuk, Saudi Arabia.

intensity (El-Shafai et al., 2007; Ansari and Khan, 2009b; Lu et al., 2010; Devlin and Witham, 1986). Physico-chemical characteristics of water determine the density, diversity and occurrence of phytoplankton in aquatic ecosystems (Sharma et al., 2016). Temperature, EC, TDS and dissolved oxygen are reported as the important environmental factors influencing the abundance and diversity of the zooplanktons (Abdulwahab and Rabee, 2015). Light reduction in the water column and enhanced organic matter load into the sediments are two main governing factors of habitat destruction in aquatic ecosystems (Olive et al., 2009). Various studies showed that the anthropogenic inputs of various pollutants into aquatic ecosystems are directly related with habitat destruction and changes in aquatic macrophyte diversity (Polomski et al., 2009). Eutrophication in coastal ecosystems is also responsible for major changes in the biodiversity of aquatic flora and fauna (Fricke et al., 2016). Temperature is another important environmental factor directly related with the functioning of an aquatic ecosystem (Ansari and Khan, 2008). The pH controls absorption of nutrients and biochemical reactions taking place in living organisms (Ansari et al., 2011b). The species diversity when studied in different aquatic ecosystems, water quality parameters like nutrient contents, light availability, water pH, depth of the aquatic body and sediments are considered as important abiotic environmental factors responsible for the biodiversity changes (Murphy et al., 2003). Aquatic macrophytes are good biological indicators and are used in monitoring and assessment of ecological health and water quality of an aquatic ecosystem (Xu et al., 2007). Studies on the life histories of dominating and decreasing species may provide an idea for the prediction and forecast on various species that are going to be threatened in near future (Candolin et al., 2008). Aquatic flora has been considered as an important tool for long term monitoring and assessment of water quality parameters as they are sensitive to any minor change in physical, chemical and biological properties of an aquatic ecosystem (Tremp et al., 1995). Aquatic macrophytes in different forms like submerged, emerged and free floating are very well recognized as ecological indicators of aquatic environment (Stojanovic et al., 1999). The species richness, relative density, abundance, biomass and evenness are also considered as important parameters for the monitoring and assessment of aquatic biodiversity (Burgi et al., 2003). Plant biodiversity is a strong biological indicator of aquatic ecosystems as it is highly sensitive to a number of factors in its surrounding habitat and it responds promptly to any change in the aquatic environment (Lorenz et al., 2003; Ansari and Khan, 2002).

Frequency, density and abundance of a species in a community are some important parameters for the measurement of plant diversity in terrestrial and aquatic ecosystems. Various models and diversity indices are useful parameters for studies on plant biodiversity. Frequency of a particular species shows its occurrence in a particular community. Density shows the strength of a species on the basis of its population within the community. It gives the degree of competition in an ecosystem. The abundance is measured to know the number of individuals of any species in an area of its occurrence. For the assessment of aquatic biodiversity various diversity indices such as species richness index, Palmer's generic index, Margalef's index are used to determine the ratio between number of species and number of individuals in a community (Hariprasad and Ramkrishnan, 2003).

The status of aquatic biodiversity has been directly influenced by human populations. Biological communities developed over millions of years and are being devastated by anthropogenic activities. The future of aquatic biodiversity is dependent on the development of national and international policies on water; the research data collected on aquatic biodiversity can also support the development of appropriate policies (Stehlik et al., 2007). Conservation biology is a new multidisciplinary science that deals with the crises confronting biological diversity. Conservation biology is used to investigate human impacts on biodiversity and to develop practical approaches to prevent extinction of species. Seasonal variations in light, temperature, wind, humidity and tidal changes directly affect the diversity of coastal aquatic flora activities which interfere with all these abiotic factors and in turn adversely affect the floral diversity. The direct and indirect anthropogenic impact on floral diversity is more important than the impacts of natural factors.

Summary and conclusions

The result of this research gives preliminary information on the diversity of aquatic flora along the coastal sites of the Red Sea at Tabuk, Saudi Arabia. It can be concluded from the present findings that the summer season is the most suitable period for collection and study of aquatic plants and suitable for the studies related to their diversity along the coastal sites of Red Sea. In a study Ajin et al. (2016) observed heavy algal bloom in aquatic ecosystems receiving nutrients in the summer season as compared to the winter. The months of April, May, June and July of summer season may be considered as the best time for collection of plants for medicinal and ecological studies as marine algal flora is a rich source of natural products and medicinally important chemical compounds (Milledge et al., 2016).

Conflict of interest

The author has no conflict of interest to declare.

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